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IRRIGATION OF RICE IN CALIFORNIA

BY

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(Based on work done at various periods during the years 1913–1916 in cooperation with the Office of Public Roads and Rural Engineering, U. S. Department of Agriculture, the California State Department of Engineering, the Office of Cereal Investigations of the Bureau of Plant Industry of the U. S. Department of Agriculture, and the California State Water Commission.)

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IRRIGATION INVESTIGATIONS

(In cooperation with Office of Public Roads and Rural Engineering, U. S. Department of Agriculture, and State Engineering Department of California)

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IRRIGATION OF RICE IN CALIFORNIA

By RALPH D. ROBERTSON

CONTENTS

TABLES

ILLUSTRATIONS

INTRODUCTION

The purpose of this bulletin is to describe the irrigation of rice in California, principally in the Sacramento Valley, where about 95 per cent of the California crop was grown in 1916. Descriptions are presented of the methods of preparing land and of the implements used, together with such data regarding use of water on rice as will cover in general the range of questions that most frequently occur to prospective rice growers in California. In addition to data gathered on rice farms throughout the Sacramento and the San Joaquin valleys, information is presented that has been gathered at the Biggs rice field station of the Bureau of Plant Industry, U. S. Department of Agriculture, where cooperative irrigation experiments were conducted during the years 1914, 1915, and 1916. The introduction of rice into California agriculture has stimulated irrigation development and the main increase in the irrigated area of the Sacramento Valley the past few years has been due to the planting of this crop.

Rice in the Sacramento Valley has served a two-fold purpose of utilizing land heretofore not used except for scanty pasture or on which grain growing has been declining through decreased production, and of providing a means of utilizing the waters of irrigation systems which had been constructed but which had not been fully developed on account of lack of settlers. As is to be expected, the industry has attracted people from Japan, China, and India, where rice is one of the principal crops grown, as well as people from the rice sections of Arkansas, Louisiana, and Texas. In many instances these settlers from other states or foreign countries have introduced some customs or practices common to their old environments, but find in California peculiar soil or climatic conditions that may call for entirely new methods. In view of this, a description of methods found best suited to California should be of value.

WATER SUPPLY AND ITS USE

Approximately 67,000 acres of rice were irrigated in California in 1916. Of this area about 29,500 acres were irrigated from Sacramento River, about 24,000 acres from Feather River, about 9800 acres from other streams, and about 3700 acres with water pumped from wells. The first commercial crop of rice in California was grown in 1912 on 1400 acres, and the area in 1916 was more than twice that planted in 1915.

The Sutter-Butte Canal, which takes its supply from Feather River about ten miles above Gridley, served the largest area of rice

in Sacramento Valley in 1916, amounting to 17,000 acres. The Western Canal, which heads in Feather River shortly above Sutter-Butte Canal, served 5500 acres. The Sacramento Valley West Side Canal, which derives its supply from Sacramento River, supplied water to 8500 acres in Glenn and Colusa counties. The Yolo Water and Power Canal, diverting from Cache Creek, irrigated about 6000 acres. Other large enterprises, which obtained water by pumping from Sacramento River, were the Moulton Irrigated Land Company, California Land and Rice Products Company, Cheney Slough Irrigation Company, Mallon-Blevins Company, and River Gardens Farms Company.

The only canal company in the Sacramento Valley serving water for rice irrigation which has as yet sold water on an acre-foot basis is the Yolo Water and Power Company, which charges $1.50 per acre-foot. The Sutter-Butte Canal Company has furnished water for rice to lands having water rights at an annual charge of $5 per acre. Recent contracts made by this company are on the basis of $7 per acre, with reimbursements to the water user for the construction of ditches and for rights of way, provided water has been used for more than two successive years. The amount of water called for in the Sutter-Butte contracts is at the rate of one cubic foot per second for each 53⅓ acres. The Sacramento Valley West Side Canal Company, by authority of the California State Railroad Commission, charged $7 per acre for rice. For this charge the water user was entitled to five acre-feet of water per acre, additional amounts to be charged for at the rate of $1.50 per acre-foot. However, no cases are known in which water used in excess of five acre-feet was charged for.

Pumping from wells for rice irrigation in California has been chiefly resorted to in the San Joaquin Valley, but to a limited extent also in the Sacramento Valley. There are many opportunities for this type of development where water can be obtained by low lifts from wells or streams either for the entire season or for a portion of the season in supplementing a gravity supply. Owing to the large water-requirements of rice and the steady demand for water throughout a long season, wells should be thoroughly tested before rice is planted and failures can be avoided by keeping the acreage commensurate with the water supply. The charge for electric power in the Tulare and Kern sections of the San Joaquin Valley is $42.30 per horsepower per annum and in the Sacramento Valley the usual rate for the smaller plants is approximately two to two and one-half cents per kilowatt hour, depending upon the size of the plant and the character of the contract. Engines burning cheap oil or distillate

may also be used. Centrifugal pumps, on account of their adaptability and ease of operation, are the most common type of pump. Twelve-inch wells are commonly used, and the usual contract price for drilling is $1.50 per foot for the first 100 feet and an increase of fifty cents a foot for each additional fifty feet.

A study of reports of the United States Geological Survey will assist those who propose to engage in pumping from wells.[1]

PREPARATION OF LAND

Land is prepared for rice in contour checks, the difference in elevation between checks varying from .25 to .30 foot where the slope of the country is from two feet to five feet per mile. Usually a surveyor is employed to lay out the field and the cost of surveying amounts to from twenty-five to fifty cents per acre. One of the most rapid methods of locating the contours, in which no stakes are required, is to have the rodman mark the location by shaking a small amount of lime on the ground from a sack. After a few points have been located on a contour, a plow team connects the points by plowing four to six furrows which form the base of the levee. Sometimes the contours or field levees are marked by lath stakes, and to avoid confusion where the contours come close together a good plan is to tie a rag of a certain color on the stakes marking one contour and to use a rag of a different color on another contour. Sharp turns in the levees should be avoided wherever possible.

Figure 1 shows a 160-acre rice field prepared for irrigation. The head ditch extends along the north line or upper end of the field and follows part way along the east side. A drainage ditch is provided at the lower end along the south side of the field, and also along the west side. The field is divided into eleven checks, the contour interval or difference in elevation between checks being .30 foot. It will be noted that there is a direct inlet and outlet provided for each check and also that several gates are placed in interior levees to admit water from one check to another. This arrangement provides good control of water from the head ditch and also offers advantages in draining the field. In case of a break in the ditch or levees the water may be quickly removed and repairs can also be made in one part of the field without interrupting the service in another.

The outside levee is made stronger than the interior or field levees and should have a base of six to eight feet and a height of 1.5 to 2.5

[1] Ground Water for Irrigation in the Sacramento Valley, California: U. S. Geol. Survey Water-Supply Paper 375A. Ground Water in the San Joaquin Valley, California: U. S. Geol. Survey, Water Supply Paper 398.

feet. There is probably no more satisfactory implement for making a strong levee than the Fresno scraper, because the team in passing back and forth over the freshly moved earth packs it down securely. The interior levees are more commonly made with a checker or ridger drawn by a tractor. Figure 2 shows a checker in use. This implement is provided with a device for raising or lowering the rear end,

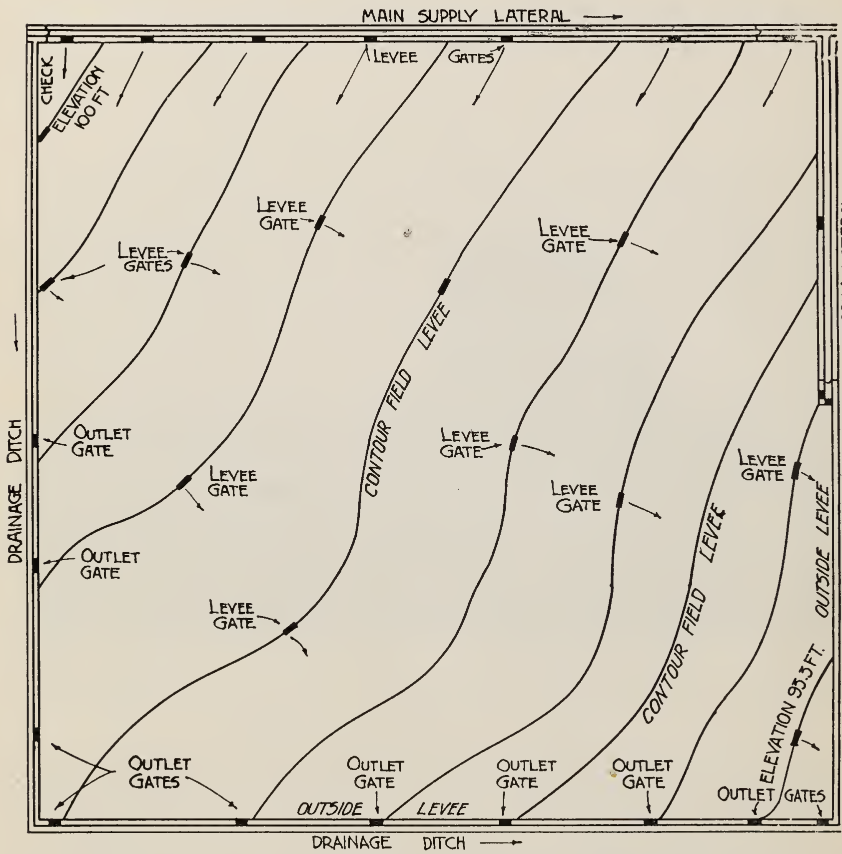

Fig. 1.—160-acre rice field, showing good arrangement of supply, drainage ditch, and contour levees.

enabling the operator to regulate the size of the levee. More often a simple home-made implement is used such as is shown in figure 3, the cost of which is about $50. The runners for sides are made of three-inch by twelve-inch plank twenty feet in length and are lined with steel. The front end is made ten feet wide on the bottom and the rear end is three feet wide on the bottom. The sides are made two feet high and are set on a batten of one-fourth to one, the tops sloping

outward. This implement makes a levee having a base of about five feet and a height when settled of about twelve inches. On fairly even ground a crew of two or three men with a tractor frequently check 150 acres or more per day. Often the work is contracted and a common price paid is $50 per day for the use of the tractor and checker. Sometimes the levees are made with a ''V'' crowder which is also widely used in making field ditches. Recently a ''V'' made of steel and reversible has come into use.

In most sections no attempt has been made to level or grade the land within a check, the preparation of land consisting mainly in building the supply ditches and constructing the levees. In the

Fig. 2.—Making levee in rice field with tractor and checker in Sacramento Valley, California.

vicinity of Willows large drags or floats drawn by tractors are used to smooth the surface after the land is plowed (fig. 4). It is doubtful if much leveling of land is justified because in fields where knolls or hummocks have been removed to fill in low places it has been found that in the ''fills'' the plant develops a rank growth of straw and the heads are not filled, while in the heavily-scraped portions of the field the plant is stunted in growth. On the other hand it must be kept in mind that a uniform depth of water over the field is highly desirable. If the depth of water is not fairly uniform there is a difference in the time of maturity of the rice and the yields are also affected, as shown in the experiments at Biggs reported later in table 3. The amount of work and expense justified in preparing the field must therefore rest largely on the judgment of the grower.

The universal practice has been to harvest within a single check on account of the obstructions offered to the passage of machinery by the present type of field levee. It is possible that as the industry

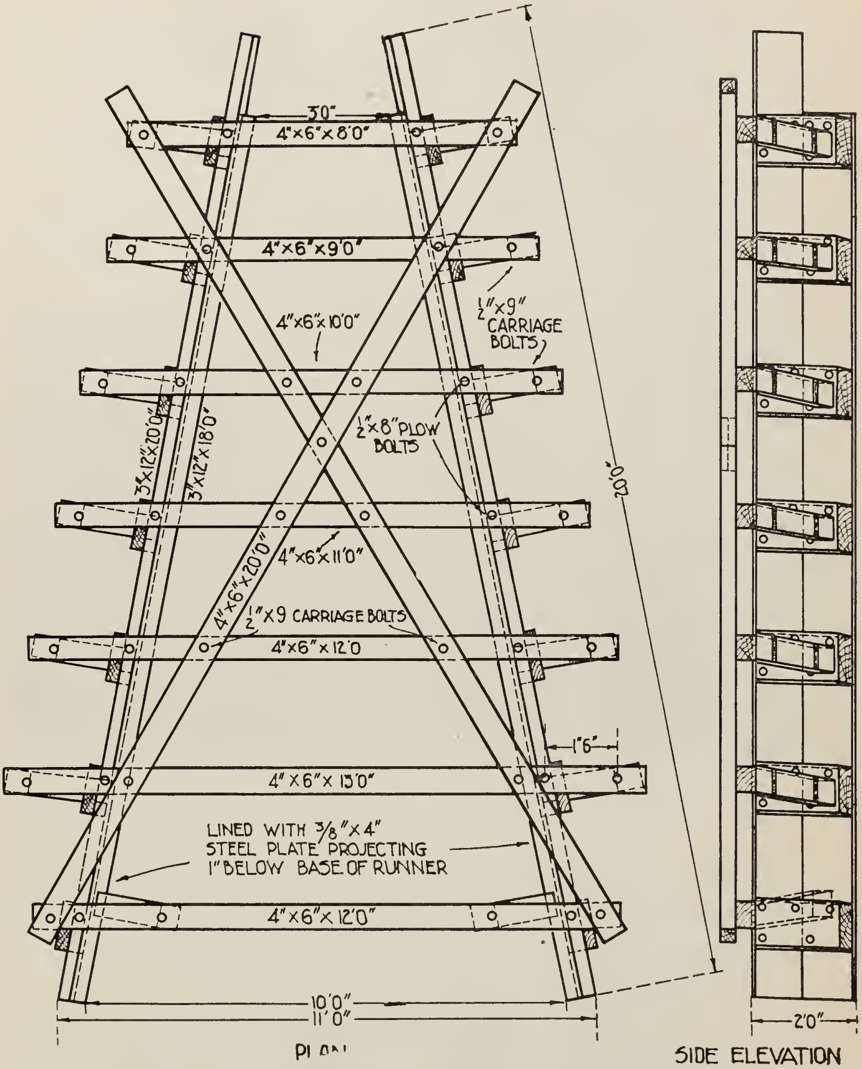

Fig. 3.—Homemade checker or levee ridger as used in rice fields in Sacramento Valley, California.

advances more permanent levees with a base of about ten feet and gentle side slopes will be used. The advantages of broad levees, besides those of ease and cheapness in planting and harvesting, are that the cultivated area is increased and weed growth can be better

controlled. It can not be expected, however, that the growth of rice on the levees will yield any appreciable amount.

GATES

Gates are necessary in the canal banks to admit water to the checks and also in the field levees for admitting water from one check to another. The canal structures are of the ordinary type used in irrigation, but the gates in the field levees are less substantial than those usually employed for alfalfa irrigation. It is important to have the gates sufficiently wide to admit the large heads of water used in the initial floodings. Figure 5 shows a simple form of wooden gate which can be installed for about fifty cents. Where the gate is more than

Fig. 4.—Heavy drag or leveller used in preparing rice land for irrigation in Sacramento Valley.

four feet wide a center division support is used. Box tubes which are sometimes placed through the levees are not generally satisfactory. The gates should be well tamped and preferably puddled in, at the time of placing them, to prevent leaks.

APPLICATION OF WATER

The irrigation season is divided into two main periods. In the first period irrigations are given to keep the soil moist, but without having the water stand on the field. In the second period the field is continually submerged. It has been found necessary to irrigate after planting to germinate the seed and to give enough subsequent waterings to maintain growth until the plant is from four to six inches high. The best time to begin submergence, according to the experiments

at Biggs, is about thirty days after the emergence of the plant above ground. The principal reason for not permitting water to stand on the field during the germination period is the danger of the seed rotting in the ground, especially if weather conditions are unfavorable and the soil is cold. As a rule, water should not be allowed to remain on the land more than one or two days after the initial flood-

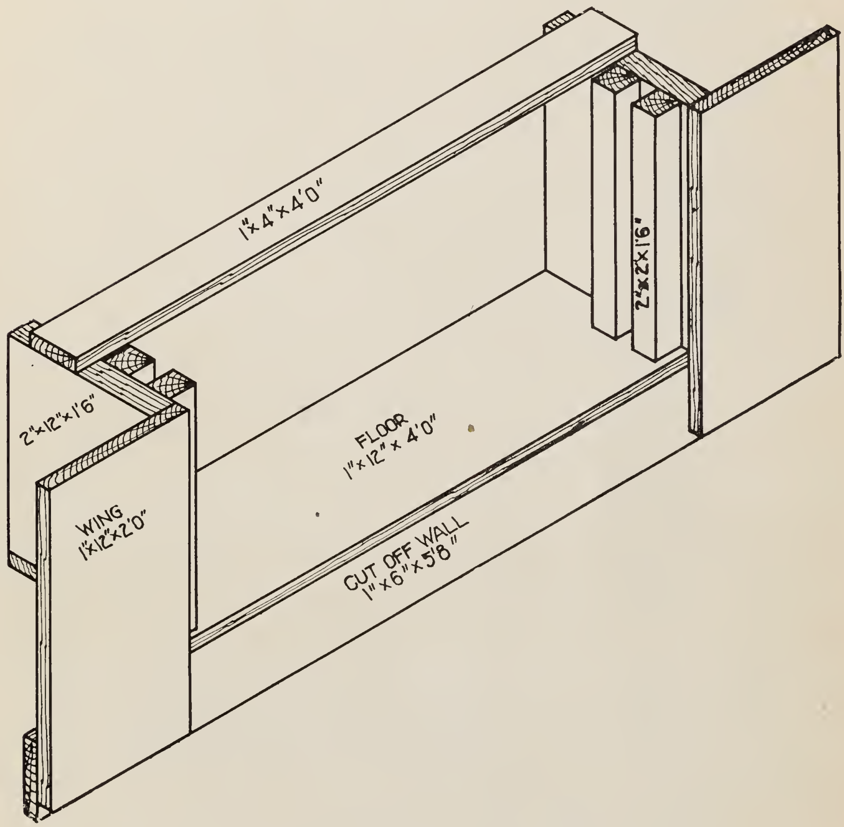

Fig. 5.—A satisfactory gate for use in inside rice levees.

ings. The use of heads of water varying from two to five cubic feet per second or more facilitates quick watering at this time. During submergence the heads need not be so large.

In beginning submergence the water should be gradually raised until an average depth of six inches is attained. Likewise at the close of the submergence period the water should be gradually lowered and not hurriedly removed, a rapid draining having a tendency to weaken the straw. Care should be exercised when draining the fields not to cause injury to lower areas. Much damage has resulted to

TABLE 1

Summary of Measurements of Duty of Water for Rice on Eighteen Fields in Sacramento Valley, California, 1916

Name and location	Area, acres	Soil type	Source of water supply	Date of first irrigation	Date of beginning submergence	Date water turned off	Length of irrigation season, days: Prior to submergence	Length of irrigation season, days: Period of submergence	Length of irrigation season, days: Total	Number of irrigations prior to submergence	Depth of water used prior to submergence, feet	Depth of water used during submergence, feet	Total depth applied, feet	Estimated or measured surface waste, acre feet per acre	Net depth applied, feet	Average area served per cu. ft. per second, acres: Period of submergence	Average area served per cu. ft. per second, acres: Whole season	Approximate depth to ground water, feet: Beginning of season	Approximate depth to ground water, feet: End of season	Yield of paddy rice, sacks per acre (averaging 100 pounds each)
				West	Side															
Harlan & Scheeline, No. 1: NE. ¼ Sec. 36, T. 20 N., R. 3 W.	135.60	Tehama clay loams and clay.	Sacramento Valley West-side Canal.	April 26	June 21	Oct. 12	56	114	170	9	1.95	5.85	7.80	0.0	7.80	39	44	6.0	4.0	33
Harlan & Scheeline, No. 2: SW. ¼ Sec. 6, T. 19 N., R. 2 W.	132.53	Tehama clay loams and clay.	Sacramento Valley West-side Canal.	May 3	June 24	Oct. 22	52	121	173	7	2.23	6.22	8.45	[2]	8.45	38	41	6.0	4.5	25
Ole Johnson, No. 1: NW. ¼ Sec. 18, T. 18 N., R. 3 W.	26.26	Willows loams, Willows clay adobe.	Sacramento Valley West-side Canal.	May 8	June 14	Oct. 30	37	139	176	4	2.69	12.14	14.83	[3]	......	23	24	5.5	0.5	15
Ole Johnson, No. 2: SE. ¼ Sec. 18, T. 18 N., R. 3 W.	75.50	Willows clay adobe.	Sacramento Valley West-side Canal.	May 17	July 1	Oct. 29	45	121	166	4	1.42	5.76	7.18	0.72	6.46	49	52	5.5	1.5	18
M. McDermott: NE. ¼ Sec. 33, T. 17 N., R. 3 W.	61.00	Willows loams	Sacramento Valley West-side Canal.	April 19	May 19	Oct. 24	30	159	189	5	1.45	10.72	12.17	3.10	9.07	42	42	6.5	4.0	47
Shaver & Edwards: NE. ¼ Sec. 20, T. 18 N. R. 3 W.	44.85	Willows loams, Willows clay.	Sacramento Valley West-side Canal.	May 22	July 6	Oct. 23	45	110	155	5	1.00	6.58	7.58	0.90	6.68	39	46	6.8	3.6	35
Spalding Company: Secs. 22, 23, 26 and 27, T. 18 N., R. 3 W.	866.00	Willows clay...........	Sacramento Valley West-side Canal.	April 23	[1]	Oct. 25	[1]	[1]	186	[1]	[1]	[1]	7.39	1.00	6.39	[1]	57	6.0	5.5	25
A. Quatman: SW. ¼ Sec. 6, T. 19 N., R. 3 W.	70.15	Willows clay...........	Pumping from wells.	April 26	[1]	Oct. 21	[1]	[1]	179	[1]	[1]	[1]	6.49	0.0	6.49	[1]	55	12.0	12.0	20
Mallon & Blevins: Secs. 14 and 15, T. 17 N., R. 2 W.	1106.00	Sacramento clays...	Pumping from Sacramento River.	April 17	[1]	Sept. 27	[1]	[1]	164	[1]	[1]	[1]	6.71	1.30	5.41	[1]	61	4.0	5.0	35

East Side

E. L. Adams: NE. ¼ Sec. 34, T. 19 N., R. 2 E.	39.50	Stockton clay adobe	Sutter-Butte Canal.	April 13	June 9	Sept. 30	57	114	171	6	1.01	3.26	4.27	0.0	4.27	70	80	1.5	1.0	39
Baker Bros.: S. ½ Sec. 28, T. 19 N., R. 2 E.	229.50	Stockton clay adobe	Sutter-Butte Canal.	April 21	June 14	Oct. 9	54	118	172	6	0.82	3.84	4.66	0.0	4.66	61	73	1.5	1.0	42[7]
Evans Bros.: SW. ¼ Sec. 22, NW. ¼ Sec 27, T. 19 N., R. 2 E.	187.23	Stockton clay adobe	Sutter-Butte Canal.	April 28	June 17	Oct. 4	50	110	160	7	1.14	3.66	4.80	0.0	4.80	60	67	1.5	1.0	34
Carl Lindberg: W. ½ Sec. 18, T. 19 N., R. 2 E.	38.80	Stockton clay adobe	Sutter-Butte Canal.	April 28	June 13	Oct. 14	46	124	170	6	1.91	7.44	9.35	[3]	......	33	36	1.5	1.0	47
Dodge Rice Company: N. ½ Sec. 29, T. 20 N., R. 1 E.	41.00	Stockton clay adobe	Western Canal ...	May 3	July 12	Sept. 26	70	77	147	6	2.50	5.78	8.28	1.02[4]	7.26	32	41	1.5	1.0	39
Conklin & Noyer: SE. ¼ Sec. 27, T. 16 N., R. 4 E.	36.70	San Joaquin loams	Hallwood Canal..	April 14	June 13	Sept. 29	60	109	169	5	2.33	10.08	12.41	2.41	10.00	28	34	.....	3.0	10
Byron Jakes (east field): NW. ¼ Sec. 28, T. 16 N., R. 4 E.	13.95	San Joaquin loams	Hallwood Canal..	April 18	June 23	Oct. 9	66	109	175	5	1.44	13.94	15.38	1.95	13.43[5]	18	26	.....	3.0	14
Byron Jakes (west field): NW. ¼ Sec. 28, T. 16 N., R. 4 E.	28.00	San Joaquin loams	Hallwood Canal..	April 15	June 24	Oct. 10	70	109	179	6	3.01	15.69	18.70	5.88[3]	......	22	28	.....	3.0	18
Schell & Woodruff: W. ½ Sec. 30, T. 16 N., R. 4 E.	172.00	Madera clay loams, Madera and Gridley loams (undifferentiated).	Hallwood Canal..	April 17	June 16	Oct. 10	60	117	177	5	1.74	7.89	9.63	[6]	......	30	37	.....	1.7	32

[1] Indefinite.

[2] Small loss through outside levee into adjacent slough.

[3] Considerable loss through outside levee into adjacent slough.

[4] Additional loss through outside levee into adjacent slough.

[5] Excessive use caused by porous subsoil.

[6] Considerable loss through and over outside levee into adjacent slough.

[7] Fifty-seven on 78 acres; thirty-five on 151 acres.

crops on lands situated below rice areas by water drained from rice fields at harvest time. In one instance many thousands of dollars worth of beans were destroyed in this way.

There has been considerable criticism in the past from millers of California rice, who claimed that the rice was cut before being fully matured. When the heads of the grain are well turned down the water should be cut out of the laterals. At this stage of maturity most of the kernels are beginning to harden. On the heel or lower part of the head the kernels should be in the dough stage. After the water is removed it is usually two weeks before the soil is sufficiently dry to permit the use of a binder in harvesting the crop.

The experiments at Biggs serve to show the best manner of handling the water on soils in that vicinity, but in sections where the soil contains alkali the usual irrigation programme may have to be modified. On alkali lands near Willows the beneficial effects of applying fresh water and of keeping it circulating through the fields were apparent. Irrigators in that section hope to reclaim the land by frequent drainage and the application of fresh water. This method is also used in portions of San Joaquin Valley on alkali soils, but where pumping from wells is resorted to the cost of water is a limiting factor.

DUTY OF WATER

Measurements were made in 1916 of the water used on eighteen representative rice fields in Sacramento Valley. This work was done in cooperation with the California State Water Commission and the results are summarized in table 1.[2] Nine of these fields were located on the west side of Sacramento Valley in the vicinities of Willows, Maxwell, and Princeton, and nine on the east side in the vicinities of Biggs, Richvale, Nelson, and Marysville. Ten different soil types were represented. The investigations showed a wide range in the net amount of water used, varying from 4.27 acre-feet per acre to 14.83 acre-feet per acre. The average depth applied to the eighteen fields was 8.23 feet and the average area served per cubic foot per second for the whole season was forty-seven acres. The difference in use was attributed to numerous factors, the more important of which were the character of the soil and subsoil, preparation of land, depth to water table, proximity of lands to sloughs, and manner of handling water. The heads of water used varied considerably in size, owing to the diversity in the size of the fields, but reduced to an acreage basis were fairly uniform. The average head used per acre on the eighteen fields was .052 cubic foot per second before sub-

[2] See also Third Report of the State Water Commission of California.

mergence and .034 during submergence. For a forty-acre field this would amount to 2.08 and 1.36 cubic feet per second, respectively.

On each of three fields where less than five acre-feet per acre was applied, the soil was a black clay adobe, underlain at shallow depths with a non-continuous hardpan with ground water approximately one foot below the surface. These fields were well prepared and the water was carefully handled, little or no water being wasted. Excessive use was found on fields close to sloughs or on land with porous subsoil and with poorly constructed outside levees.

On the Adams field included in table 1, measurements were made of the water used in 1914, 1915, and 1916, the data for these years being given in table 2. This field is located about three miles northwest of Biggs and comprises 39.5 acres in the NE ¼, sec. 34, T. 19 N, R. 2 E. The soil is Stockton clay adobe typical of large areas utilized for rice growing in Butte County.

TABLE 2

RESULTS OF MEASUREMENTS OF THE USE OF WATER ON THE ADAMS RICE FIELD NEAR BIGGS, 1914, 1915, AND 1916

Year	Date of first irrigation	Date of beginning submergence	Date water was turned off	Number of irrigations prior to submergence	Depth of water used prior to submergence, ft.	Depth of water used during submergence, ft.	Total depth applied, ft.
1914	April 29	June 12	October 12	6	1.04	3.61	4.65
1915	April 21	June 9	October 1	7	1.37	3.50	4.87
1916	April 13	June 9	September 30	6	1.01	3.26	4.27

Taking the three-year period, the average total depth applied was 4.58 feet and the average length of irrigation season from the time of the first irrigation until water was turned off was 167 days. The field was planted to Wataribune variety, a short-grain rice which comprises the greater part of the acreage of rice in California. Yields of approximately 6000, 4500, and 3900 pounds per acre were obtained in the years 1914, 1915, and 1916, respectively. Especial care was given to this field and the yields were above the average.

The amounts of water used on this field probably represent the minimum use under gravity canals in Butte County and show what can be accomplished with careful handling of water on well-prepared land.

In connection with the above measurements, records of precipitation and evaporation from a free water surface tank were kept by

the Bureau of Plant Industry, U. S. Department of Agriculture, on the Biggs rice field station which adjoins the field.

The amounts of rainfall and evaporation in the periods corresponding to the irrigation season for the years 1914 to 1916, inclusive, are given below:

Year	Precipitation during irrigation season, feet	Evaporation during irrigation season, feet
1914	0.21	2.91
1915	0.36	3.17
1916	0.13	3.48

Fig. 6.—Rectangular weir and water register used for measuring irrigation water on Adams rice field, near Biggs, California.

Measurements of the water used were made by means of a standard contracted weir and automatic water register shown in figure 6. Average heads of two to five cubic feet per second were used in the initial floodings, while an average flow of .50 to .75 cubic foot per second was continually run during the period of submergence.

It is interesting to compare the irrigation practice and data for rice growing in California with those of the rice sections of Arkansas, Louisiana, and Texas.[3] In those three principal rice-growing states all but 2.5 per cent of the irrigated land in rice is supplied with water by pumping, and wells afford a supply for about one-third of this area. For prairie lands the pumping machinery is generally designed

to provide seven and one-half gallons of water per minute for each acre irrigated, which is equivalent to a flow of one cubic foot per second for sixty acres. For the alluvial lands along the streams ten gallons of water per minute per acre is provided, while thirty-eight to forty gallons per minute per acre is sometimes required if the soil is a loose, sandy loam, with a porous subsoil, and is located near a river. The average length of the irrigation season in the rice sections of Arkansas, Louisiana, and Texas, extending from the time of the first application of water until it is removed to permit harvest, is about eighty-six days.

The fact that more water is required to mature rice in California than in the rice sections of the south is ascribed principally to the difference in climate. The nights are much warmer in the southern states than in California and there is less difference in the daily range of temperature. The number of days that water must be used to mature rice in California is, therefore, much greater than in Arkansas, Louisiana, or Texas. The rainfall during the irrigation season in California is practically negligible, while in the southern states it may amount to ten or twenty inches. The evaporation in California is generally over twice that in the south. Fortier reports that measurements have been made of rainfall, evaporation, and the duty of water for irrigating rice on prairie lands of Louisiana, Texas, and Arkansas for eleven years, during which twenty-one measurements have been made.[4] The averages of these measurements give 15.74 inches of pumped water applied to the land and 17.16 inches of rainfall, and a loss due to evaporation from flooded rice fields of 15.33 inches.

DRAINAGE

Facilities for drainage are almost as important as for irrigation. The planting as well as the harvesting depends largely upon the condition of the field, and on heavy clay soils which naturally dry out slowly drainage is a most important feature. Poor drainage results in low places remaining wet and not only delays planting, but also impedes the progress of heavy harvesting machinery. Thorough drainage is the only solution for removing alkali salts and for relieving water-logged lands.

In sections where drainage is naturally poor the growing of rice with its heavy application of water tends all the more to increase or intensify the needs of drainage. Any effective means of controlling weeds that now menace the rice industry and conditions that will

[3] U. S. Dept. Agr., Farmers' Bul. 673.

[4] Use of Water in Irrigation, 1 ed., p. 229.

make possible a rotation of crops must depend largely upon adequate drainage. The people of Richvale, realizing the need of lowering the water table which has risen to within a foot of the surface, recently voted $150,000 for drainage. The formation of drainage district No. 833, including lands west of Biggs and Gridley, is a hopeful sign of meeting the problem in that portion of the valley. The opening up of natural water courses and the construction of a comprehensive drainage system in keeping with the flood control work now being undertaken in the Sacramento Valley is likely to have an important bearing upon the future of the rice industry in California.

Fig. 7.—One-fifth acre plat on Rice Experiment Station near Biggs, California, on which submergence was begun thirty days after emergence of plants.

RESULTS OF EXPERIMENTS IN RICE IRRIGATION

Experiments in rice irrigation were carried on for the years 1914 to 1916, inclusive, in co-operation with the Bureau of Plant Industry, U. S. Department of Agriculture, on the Biggs rice field station. The objects of the investigations were to determine the effect of varying dates of submergence of land, varying depths of submergence of land, the effect of no continuous submergence, as well as the effects of stagnant and slowly-changing water. Attention was also given to fluctuating the depth of water during submergence to determine the effect on the growth of the plant. The tests were made on ⅕-acre plats (fig. 7) enclosed by well-constructed levees and arranged so that

they could be irrigated and drained separately. The soil is a black clay adobe typical of lands utilized for rice growing in the vicinity of Biggs and Gridley. Results of the experiments are given in table 3.

TABLE 3

EFFECT OF IRRIGATION METHODS AND TREATMENT ON YIELDS AT BIGGS RICE FIELD STATION OF THE BUREAU OF PLANT INDUSTRY, U. S. DEPARTMENT OF AGRICULTURE, 1914, 1915, AND 1916.

Irrigation treatment	Yield per acre, pounds			
	1914	1915	1916	Average
Beginning submergence fifteen days after emergence of plant	4510	3860	3750	4040
Beginning submergence thirty days after emergence of plant	5610	4270	4020	4633
Beginning submergence forty-five days after				
Beginning submergence sixty days after emergence of plant	5410	4100	3890	4466
Submergence maintained two inches deep	5010	4030	3620	4220
Submergence maintained four inches deep	5490	4290	3760	4513
Submergence maintained six inches deep	5670	4510	3900	4693
Submergence maintained eight inches deep	5220	4400	3940	4520
Slowly changing water	4790	4210	3460	4153
Stagnant water	4940	3990	3800	4243
No submergence (soil kept moist by frequent irrigation)	2440	2480	2100	2340
Fluctuation of depth	5290	4160	3690	4380

Each year the best results were obtained by commencing submergence thirty days after emergence of the plant. In 1914 and 1915 the heaviest yields were secured by maintaining a uniform depth of six inches over the land during submergence, but in 1916 the plat submerged eight inches deep gave the heaviest yield, although the increase in yield only amounted to about 1 per cent over the plat submerged six inches deep. Where no water was held on the land, but the soil was merely kept in a mucky condition, only about one-half of a normal yield was secured and the rice was of poor quality. There was little difference in the yield from the plat which received slowly-changing water and from the plat which had no water removed. No reaction on the growth of the plant was shown from fluctuating the depth. In this experiment a uniform depth of four inches was maintained until "booting" was noticeable. Then the water was lowered to a depth of one and one-half inches. The water was held at this depth until the first heads appeared, when it was applied to a depth of four inches and maintained there until the rice was ready to be drained. This scheme is said to hasten the maturity of the rice in the southern states, but apparently has no appreciable effect here.

In order to determine the maximum and minimum temperatures of water at the various depths of submergence, records were taken daily at 8 A.M., 1 P.M., and 5 P.M. The readings for the shallow depths of water showed higher temperatures during the day and lower temperatures during the night than for the greater depths of submergence. The most uniform temperature was obtained on the plat submerged six inches deep. It is probable the yields are affected to a considerable extent by the daily range of temperature.

SUMMARY

Approximately 67,000 acres of rice were irrigated in California in 1916, the water supply being obtained principally from Sacramento and Feather rivers. Only about 3700 acres were irrigated by pumping from wells.

Land is prepared for irrigation in contour checks, preparation consisting mainly in making ditches and levees and installing gates. The gates must be wide enough to admit the large heads of water used in the initial floodings.

The irrigation season consists of two periods. Frequent light irrigations with relatively large heads of water are given to germinate the seed and to maintain growth until the plant is four to six inches high, and thereafter the land is continually submerged to a depth of six to eight inches until the rice is matured.

Measurements of the use of water in 1916 on eighteen typical fields in Sacramento Valley showed a range of from 4.27 to 14.83 acre-feet per acre, an average depth applied of 8.23 feet, and an average of forty-seven acres served per cubic foot per second. The heads of water used per acre averaged .052 cubic foot per second before submergence and .034 during submergence. The lowest use was on fields with heavy retentive soil, where the preparation was good and the water carefully handled. The average annual use over a three-year period on a field near Biggs was 4.60 acre-feet per acre. During the three irrigation seasons the average precipitation was 0.23 foot and evaporation 3.19 feet. Irrigation practice and requirements in California differ from those in the Gulf states, due mainly to different climatic conditions.

Adequate drainage is essential to successful rice production. Planting and harvesting are both delayed while the soil remains wet, and the removal of alkali salts and the relief of water-logged lands are dependent upon drainage facilities.

The results of experiments made in 1914 to 1916, inclusive, on black clay adobe soil near Biggs indicated that thirty days after emergence of the plant is the best time for commencing submergence, and that six inches is probably the most advantageous depth of submergence. Very poor yields were secured where no water was held on the land. Fluctuating the depth of water had very little effect on plant growth. More uniform temperatures of the water were found with the greater depths of submergence.